Levels and corresponding switch states engineering essay

Engineering

1. 1 IntroductionThe rising awareness of climate change and the negative contributions of fossil energy flanked by its increasing decline over numerous decades have brought more interest of solar energy and its numerous advantages to the attention of policy makers and academics alike. On one hand, solar energy transmitted through photovoltaic systems are said to be abundant, inexhaustible and renewable while such energy on the other hand are said to hold numerous advantages for the environment and in line with the concept of sustainable development. Rising from this increasing interest, the commercialization of solar projects have exploded in the past 5 years especially from Middle East countries where there is abundant sun which is the main source of power for solar energy generation. However, there are many issues relating to efficiency and performance of solar projects observed in existing projects around the world, some of which mostly occur in the energy generation phase (Pires et al, 2005). To achieve optimal energy transmission from (dc) to (ac), the classical three phase two level inverter are said to weak as they often lead to higher switching losses because of their low power handling capability and reliability. Moreover, this traditional inverter system and other conventional form of inverters are known to have square shape line current which leads to

heating of the power transformer system given its higher �order harmonic contents. Interests have grown in multilevel inverters as a result because such topologies have more advantages and have less distortion effects while they are known to reduce dv/dt distress (Alonso-Martinez et al, 2010). Multilevel inverters also have the advantage of working with other different renewable energy functions like fuel cells, batteries, wind turbines, etc and therefore can be used in an hybrid energy system. Its outputs are in waveforms which support the system function of reducing harmonics (Sarwar et al, 2009). Sarwar et al suggests that multi level system works by synthesizing the ac voltage from other voltage levels on the dc system and as the different voltage levels on the dc side rises, there is more steps added to the synthesized output waveform, thus generating a wave in the form of a staircase which move towards the sinusoidal wave with the possible lowest amount of harmonic bends (Sarwar wt al, 2009). Its numerous advantages make the multilevel system suitable for PV applications particularly given that PV arrays through their modular structures allows different DC voltage levels to be easily synthesized. In some part of the voltage cycle, the power flow is from the ac source to the load and in some part of the cycle it is vice-versa. Given the numerous functions and advantages of multilevel inverters, the aim of this dissertation was to design and build a multilevel inverter connected to a photovoltaic array. Focusing on Middle East region specifically the Saudi Arabian desert and the ongoing solar projects, the study will explore the functioning of a multilevel and their operating principles as well as how multilevel inverters can improve energy efficiency, capacity and surge power. Recent moves by the Saudi government have pointed the country to the direction of a potential solar energy leader in the world. The government in 2012 approved over �80 billion for the launching of a solar project in the Arabian Desert while promising more commitment to put more investment in the coming years to produce abundant solar energy for the country�s energy self sufficiency. Arising from the project has not only been concerns of ensuring that energy conversion matches energy generated given that the Arabian Desert due to its higher sun radiation generates optimum energy but also because the solar energy has been criticised as not offering efficiency gains over other sources of energy. Incorporating a multilevel inverter topology as argued by many can help to improve the problem of efficiency by ensuring reduced voltage losses and high conversion capacity. Characteristics of heat, dust and humidity which mark the Arabian Desert are factors which have been identified as problems of the Saudi solar project. However, with multilevel inverters, some experts argue that efficiency can still be maintained nonetheless given than the system offers high capacity in case of low output harmonics which could result from heat and dust problems. Another importance in multilevel inverter as related to the Saudi project is that they can be connected to the grid directly and therefore ensures there is no need for transformers � the advantage of leads to overall cost efficiency. The main problem associated with multilevel inverters however are that there large numbers of switches can make it complex thus reducing the potential efficiency it can provide. The present dissertation proposes a cascade H bridge model of multi level at different levels with fewer switches. With reduced switches, there can be better control, less implementation costs and reduction in overall weight.

These advantages will make it more applicable to GRID connected solar PV systems (See Simulation results in chapter 4). Based on the proposed model, the following chapters present a critical of the literature discussing all the available topologies and their advantages. The modulation results as well as model and configuration of the proposed structure is discussed. The conception of this chapter follows the general course and objective of the dissertation which is outlines in the following section. 1. 2 Research Aims and Objectives* Understand the general principles of multilevel inverters* Propose a design of multilevel inverters based on cascade H Bridge low switch model* Simulate 3levels with 4 switches, 5levels with 8switches and7 levels with fewer switches, and analyse the result* Evaluate the design in relation to the Saudi solar PV project1. 3 MotivationThe chief motivation behind this dissertation was to develop a simulation model of a multilevel inverter topology in relation to the Saudi solar power project. As is common with most commercial grid connected solar system in the Middle Eastern Arabian Desert, it has been observed that the issues of temperature, heat and dust pose huge problem to solar efficiency and implies double costs and low performance (Kurram, 2010). In recognition of the problem, project managers in Saudi solar development have adopted different multilevel inverter topologies. However, inspite of the adoption, several frustrations are still reported, one being the numerous switches involved in managing the multilevel inverters as well as the complexity it poses to managing the huge commercial projects. The managers argue that the complexity involved in the multiple switches can have many negative effects can raise many questions about the technical management and sustainability of the solar project as a whole. In acknowledgement of other problems encountered through the country�s solar project, the model in this dissertation was developed to offer more convenience and less complexity in such large projects as well as the possibility of reducing costs while improving efficiency. In view of the foregoing, this dissertation will offer a new method of improving the capacity and performance of multilevel inverters in the face of high costs and complexity of traditional models. In addition, the dissertation was designed to improve knowledge on the operational principles of multilevel inverters and the current issues inherent in their different conceptions. 1. 4 Dissertation OutlineFollowing the present chapter which is the introduction where the objectives are discussed. Chapter 2, the literature review presents a discussion of the different types of multilevel inverters as well as their advantages and their structures. The chapter also examines issues of performance and efficiency as well as problems often encountered in different levels of multilevel inverters. This is followed by the third chapter, the Methodology where the proposed models was discussed. The chapter also discussed the research design and the approach taken to the simulation of the proposed model. Chapter four, the Analysis and discussion follows by presenting the simulation results as well as the modular scheme with a discussion of the advantages and possible issues in the model. The simulation is compared to other models and highlights its advantages over others. Chapter five is the conclusion which evaluates the proposed model and some of its implications for the Saudi solar project and the future of solar energy adoption. Finally, based on the issues highlighted in the dissertation, a suggestion is given for future studies. Literature

Review- Chapter 22. 1 Multilevel inverterThe explosion of numerous industrial power applications over the past recent decades has necessitated the need for stronger apparatus that can support different voltage drives at different power levels. Multilevel inverters through the use of high semi conductors support the switching of higher voltage DCs to perform power conversion to alternating current by creating a staircase voltage waveform (Khamfoi et al, 2009). The model of multilevel inverters was introduces in 1975. In the definition of Chiasson et al (2005), a multilevel inverter is a power electronic apparatus designed to fuse a desired AC voltage from defferent levels of DC voltages. A multilevel inverter has many advantages over traditional inverter systems based on its staircase waveform quality as well as common mode. Based on the common mode quality, multi level inverters have the ability to perform at both high and fundamental switching levels while at the same time able to draw input currents with low distortion (DuLeon et al, 2006). According to (Tolbert and Habetler, 1999) the problems with multilevel inverters are that they do have some functional issues which mostly pertain to the greater amount of semi conductors switches usually required. This usually makes it intricate and costly to pay for. Researchers have put forward different topologies of multilevel inverters. However, three major topologies have been well identified in the current literature. The three topologies are known as: flying capacitor, cascade H-bridges with dc sources and diode clamped also known as neutral clamped. Manjrekar et al (2000) have put forward a topology based on the use of two separate DC sources coupled with the utility of AC power. Similarly Zhong Du et al (2006) under the H-bridge topology have put forward a multilevel inverter using a single source without transformers. The first introduced was a three level multi inverter which further lead to the concept of a multilevel inverter. A multilevel inverter is more advantageous over the conventional form where the modulation used is the pulse width form. The important characteristic of a multilevel inverter include the following:* Input current: Low distortion current is drawn using multilevel inverters.* Staircase waveform quality: A series of power MOSFET switches are combined with several low voltage dc sources so that power conversion takes place by producing a staircase voltage waveform. With multilevel inverters, electromagnetic compatibility problems are reduced to a minimum because the output generated has a very low distortion and can even reduce dv/dt stress.* Switching frequency: The best advantage of multilevel inverters is that they can operate at both high switching frequency as well as fundamental switching frequency. When the switching frequency is on the lower side, it means efficiency is higher and the corresponding switching loss is low.* Common mode voltage: A small level of CM voltage is produced and can be eliminated using several advanced modulation techniques. During the last two decades several multilevel inverter topologies have been proposed. Basically, there are three major multilevel inverter topologies applied in industrial electronics. These include flying capacitors, cascaded H-bridges converter and diode clamped. Following is the study of various multi level topologies in detail. The three main topologies are explained in the following sections: 2. 2 Cascade H-bridgeCascade multilevel inverters first appeared in (1988) but became known in the (1990s). It is a topology that is mostly used in MV greater-power voltages (highest rates been 13. 8 kV, 1400 A, and 31 000 kVA) based on its modular configuration and power-quality functioning features (Rodriguez et al, 2002). In a single phase structure of a cascaded inverter, several different dc sources are connected to H-bridge inverters. Each inverter port is adjusted to generate three distinct voltage outputs. Four different switches are combined differently to produce different outputs. For instance, S4 and S1 are turned ON to obtain +Vdc and S3 and S2 are turned ON for obtaining �Vdc and so on. When all four switches are turned ON, output voltage produced is zero. The model is connected by numerous power cells with every cell having a distinct rectifier and 3L H-bridge inverter, as well as a capacitive dc-link with an independent voltage source included. Where n is the cell numbers, 2n+1 is the number of voltage levels in total. In the observation of Singh et al (2012) this topology has the advantage of utilizing fewer components in contrast with other models; therefore it is less costly to operate. (�K. J. McKenzie�, 2004) Three voltage outputs are usually generated within every single phase of a 3 level inverter: +Vdc, 0, -Vdc by linking the DC source to the AC output by synthesizing four different switches, S1, S2, S3, & S4 - in order to get +Vdc, switches S1 and S4 are turned on, while �Vdc in obtainable using S2 and S3 switches respectively. When the four switches are on 0 is the voltage output (See figure 1). There is a connection between the every full-bridge inverter levels and AC outputs in a way that the combined voltage waveform is the summation of the total outputs of inverters (Tolbert and Hebetler, 1999). Figure 1Figure 1 Single-phase structure of a multilevel cascaded H-bridges inverter2. 3 Flying CapacitorIntroduced in 1992, by Maynard and Foch, the flying capacitor based inverter is very similar in structure to a diode clamped inverter. The only difference being that instead of using clamping diodes, inverter makes use of capacitors in replacement. The topology of this inverter has dc side capacitors laid across a ladder structure where the voltage differs in each capacitor. The increment in the voltage level between two capacitors determines the size of output waveform produced. As shown in figure 1. 2, this topology is based on a ladder structure of DC side capacitors, where there is distinction in the voltage on each side of the capacitor � thus allowing for increase in voltage levels between two capacitor legs which gives the size of the voltage step in output waveform. (�Tolbert and Hebetler�, 1999). Figure 2 Flying capacitor multilevel inverterOne major benefit of this model is that one switch can synthesize an output voltage therefore this provides the option of charging/discharging specific capacitors or incorporating them in the control system to help balance voltage levels across the various power changes. The flying capacitor at the m-level will require (m-1) ? (m-2)/2 auxiliary capacitors per phase if the voltage rating of the capacitors is identical to that of the main switches. (Khamfoi et al, 2009). 2. 4 Diode-Clamped Multilevel InverterAkagi, Nabae and Takahashi together proposed a three level diode clamped inverter in 1981 which was essentially a neutral point converter. There is a commonly connected dc bus for all of the three phases. The dc bus is further divided into six different levels using five capacitors. Vdc voltage flows through each capacitor. Based on the author�s proposition, the topology consists of five subdivided capacitors divided into six. The voltage within every of the individual capacitor is Vdc, with every switching device been Vdc from the clamping diodes. Figure 1. 3 shows outlines the output levels that are possible for each step of the inverter with the negative dc voltage V0 provided as a reference. Figure 3Diode-clamped inverterTable 1 Diode-clamped six-level inverter voltage levels and corresponding switch statesPart of the element of a line voltage Vab is a phase-leg a voltage and a phase-leg b voltage which results in an 11-level staircase waveform. This indicates that an m-level diode-clamped inverter has an m-level output phase voltage and a (2m-1)-level output line voltage. While every switching device is required to obstruct only a voltage level of Vdc, the clamping diodes require different ratings for reverse voltage jamming. Using phase a of Figure 31. 5 as an example, when all the lower switches Sa�1 through Sa�5 are turned on, D4 must block four voltage levels, or 4Vdc. 2. 5 Basics of a Multilevel inverterThe circuit shown below is a simple topology of a multilevel inverter topology used for implementing several multi stage inverters. It is based on the concept of simple four level switch inverter used either for single or dual phase inverters. These inverters produce three different levels of voltages namely +Vdc, Zero and �Vdc. DriverLoadFigure 4 Three level module for constructing multilevel invertersThe DC power supplies of four inverters are secluded and the dc supplies are levelled with three levels of voltages. (�S. Sirisukprasert, J. S. Lai, and T. H. Liu�, 2002) The scaling of voltages is in power of three which permits usage of four inverters with four different levels of output voltage. The inverter located at the bottom of the circuit is known as the master while the rest of the circuit modules are known as slaves. An additional plus factor of this topology is that the master works at a lower switching frequency. Connected to a four stage converter, it can follow a sinusoidal waveform and control the voltage at load as an AM module. Figure 5 Voltage amplitude modulation using a four stage converter2. 6 Power DistributionMost of the power delivered is contributed by the master. A pure resistance at load is fed with the help of a sinusoidal voltage. Master inverter delivers more than 80% of the real power output while a meagre 20% is delivered through slaves. Furthermore, the second and the third slave only deliver 5% of the total power output. This concludes that the dc power sources required by the slaves are extremely small.

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Figure 6 Active power distribution in a four stage multilevel inverter2. 7 General multilevel topologyPeng [34] proposed a new topology called P2 topology which is rather known as a generalized multilevel topology which helped in deriving the present multilevel inverter topologies such as capacitor clamped multilevel inverters and diode clamped multilevel inverters. The advantage of the generalized multilevel topology is that it balances each voltage level on its own irrespective of load characteristics and with no help from other circuits at any number of levels. Thus, this is a complete multilevel topology that further enhances the existing topologies. Any desired inverter with desired number of levels including the old bi-level inverter can be attained by using the generalized topology structure. 2. 8 Mixed level multilevel inverterSeveral different multilevel inverters are combined in different forms to serve some useful purposes. This is known as mixed level or hybrid multilevel inverter. For instance, in order to cut short the number of secluded DC sources for high voltage, either of the diode clamped or the capacitor clamped inverters could be used as an alternative for the full-bridge cell in a cascaded inverter. The circuit configuration makes use of hybrid mixed level multilevel units as multilevel cells form the building blocks of the cascaded inverter. The basic advantage of this topology is that it requires less number of secluded DC sources. However, the only disadvantage of this kind of generalized topology . 2. 9 Current source and voltage source multilevel invertersWith a 36-step input waveform, various newly designed voltage and current source multilevel inverters have been proposed. There are basically two main power inverters both of them fixed with harmonic repelling AC side reactors and another inverter joined with dc side inter phase transformers. The task of the attached inverter is to inject into the voltages or ripple currents possessing a frequency six times of line frequency. Owing to their low switching frequencies and distortion, both the current and voltage source multilevel inverters are well suited for high power applications. In order to compare both these, one can compare the system configuration and operational settings. 2. 10 Amplitude width modulationThe process where one or more than one properties of the analog or digital signals are varied such that the respective signals can travel longer from the respective source to a fixed destination is known as modulation. While travelling sound waves travel through air and in the medium get absorbed by several objects and particles and hence do not travel a longer distance. In order to make it travel a larger distance, the signal is modulated such that it is not absorbed by the particles in the medium or the effect of absorption is less. In case of amplitude modulation, the amplitude of high frequency wave is modulated according to the intensity of the signal. (�L. M. Tolbert, and T. G. Habetler�, 1999)The Amplitude width modulation is a control strategy where the dc input voltages have been used as a staircase by firing the switches at different angles. In this strategy, the aim is not to control the width as in some application such as driving a motor or controlling the speed. The goal is to have as much amplitude with a constant width across the wave diagram. It is worth known that the increase of switching frequency is not because of the large number of switches, the switches frequency rises due to the increase of the switching angles. The proposed 5 level inverter is using PWM with a fixed width firing angle. The reason for that is to have more voltage outcome at the load with less switching frequency which results less power dissipation (Ghoreishy, 2010). A high frequency carrier wave is changed in amplitude with respect to the intensity of signal, it is known as amplitude modulation. This means only amplitude is changed with respect to frequency and phase of the carrier waveform. (�L. M. Tolbert�, 1999)2. 11 Comparing a multilevel inverterOn comparing three different topologies of multilevel inverters with reference to weight, cost, power, losses and THD it is found that there are two types of multilevel inverters namely, 5-level and 9-level. Both these inverters are connected to 75kw and 400 V asynchronous motor. In order to make the comparisons more precise, MOSFET�s and IGBT�s are used as switching devices. A 9-level inverter has a lower THD as compared to a 5-level and a 2-level inverter. In order to save cost, a 2-level inverter should be used as it is the most cost-effective. In case weight is more important, a 2-level inverter should be used. It weighs about 5Kgs. Flying capacitor on the other hand is the best choice if power plays an important role. Hence, in order to select an inverter, what�s more important is to select the parameter which is more important. (�K. J. McKenzie�, 2004). 2. 12 Use of multilevel inverters in solar PV projectsWith a reasonable life span and high investment, photovoltaic array makes it mandatory for the customer to pull out maximum power output from a PV system. The non-linear current voltage characteristics of a PV array and the revolution and rotation of the earth round the sun, further highlights the usage of maximum power point tracking of the system. In this scenario, grid connected PV systems have gained special importance due to the fact that they do not require battery backups to ensure maximum power point tracking. Unlike these, stand alone systems are also equally capable of achieving maximum power point tracking but they do require a suitable battery back up for this reason. There are usually two main stages in grid connected PV systems such that the available solar energy is properly fed into the grid. Through the first stage, PV array voltage is boosted and the maximum solar power is traced. While in the second stage, the dc power produced in the first stage is converted into high quality ac power. Usually, the first stage is laid with a boost or a buck boost type dc-dc inverter topology. These types of two stage set ups are well tested and operate well. At the same time, there are a few loopholes of such a configuration as well. These include low reliability, large size, high part count, high cost and low efficiency. Now, in order to minimise the power processing stages in such two stage systems, there are two simple solutions proposed to this need. These include: 1. Making use of an array with a high enough PV voltage which can be obtained with the help of series string modules connected with cascaded H-Bridge inverter. 2. Secondly, making use of a usual H-bridge inverter connected with a step-up transformer. Although these options are very much viable, they do have certain loopholes. Most importantly, with a transformer added to the grid, the bulkiness and cost of the set-up increases by many folds, other losses kept aside. Apart from this, Fed with a high dc voltage, a PV array also suffers from several drawbacks. Some of them include reduced protection, Hot-spots experienced during half shading of the array and high probability of leakage current through parasitic capacitance in between the ground system and the panel. It should be noted that in both the options, the inverter configuration must definitely take care of the MPPT. However, the best way out is to have just a single power electronic carrier in between the grid and the PV array to gain all the functions such as boosting and inversion, electrical MPPT in order to achieve a much compact and light weight system. Some other advantages of such systems include high performance, light weight, protective, high reliability, cost effective and low electromagnetic interference and they are hence most suitable for modern day highly integrated systems. So, smaller the number of power stages, simpler goes the module integration. Mostly multilevel inverter configurations have been designed to overcome the drawbacks of a compact state switching device such that they could be used for high voltage electrical systems. With the usage of unique structure of multilevel inverters PV systems can attain high voltages and low harmonics without any usage of transformers. This factor makes such unique multi inverter topologies best suited for custom power applications and ac transmission systems. Also, multi level inverters find best usage in distributed power systems due to their ability of controlling frequency and output voltage and reactive power flow at dc/ac interface. In fact the general role of a multi level inverter is to produce a desired ac voltage output from several different levels of dc voltages. This makes multilevel inverters ideal for connecting in series or in parallel an ac grid renewable energy sources like fuel cells or photovoltaic�s with batteries and capacitors as energy storage devices. Some other applications of multilevel inverters include the following: 1. Dynamic voltage restoration2. Speed adjustable motor drives3. High voltage dc4. Static vary compensation and5. Harmonic filteringTo sum up all, a photovoltaic inverter is basically the heart of a PV module which performs the task of converting dc power attained from PV modules to ac power to be fed into the grid. A classical two level inverter feeds the circuit and this leads to a poor quality voltage and current waveform. Hence, multilevel inverter technology is used for medium to high voltage range uses and also used widely in the power engineering community such as power conditioning uses, HVDC link, power quality and adjustable speed drives. In fact, these days multilevel inverters have gained excessive importance for manufacturers and researchers due to the fact that they are more advantageous over conventional pulse width modulated inverters. Some of the basic advantages of multilevel inverters when compared to conventional two level inverters are listed below: 1. Low dv/dt. 2. Small filter size. 3. High voltage capability. 4. Low EMI. 5. Improved output waveform. 6. Low harmonic distortion. 7. Low switching loss. In order to improve the waveform at the inverter output, harmonic content of a waveform has to be reduced and filter size to be minimized and Electromagnetic interference generated at a particular level due to switching operation of an inverter. Furthermore, a multilevel inverter is much capable of producing a much higher voltage at the output than the voltage rating of every switching device which includes lower harmonics at a somewhat low switching frequency. Harmonic reduction is however limited for some topologies of a multilevel inverter with control strategies. This does not applies to all though. Above all, due to a relatively high conversion ratio a DC-DC inverter finds its usage in a power conditioning system which leads to quick response characteristics. (�L. M. Tolbert�, 1999)The economy of the Middle East (Saudi Arabia) is bestowed with a huge plethora of natural resources that well support the development and proceedings of its industrial sector. Moreover, as the country is connected to the river Nile, it promises a perfect atmosphere for the set up of hydro electric power stations. On the other hand, hydro power is simply a base source which leads to several other supplementary forms of power sources. In order to support and supplement hydro power, two diesel power stations and Namanve thermal power are commissioned. At the same time, it would not be a good option to use Diesel power due to its present and future effects due to carbon emission and the other like pollutants that are sent to the atmosphere via diesel. Hence, an alternative power source which is capable enough of supplying additional power and assuring a healthy and sustainable environment. Studies are still being carried out to find out the best suitable alternative to diesel as an electricity source and one such device is solar photovoltaic systems. 2. 13 summaryThis literature review of the dissertation provides a brief synopsis of multilevel inverter circuit topologies and their switch strategies. Several applications that make use of inverter circuits have been discussed in detail above. These days, there is more usage of multilevel inverter based models and hence there is a high degree of research and development being conducted on technologies related to multilevel inverter. There is a higher degree of liberty with traditional two level power width modulation as compared to multilevel carrier based power width modulation. In case of multilevel power width modulation, the switching frequency which is a function of modulation waveform and carrier set is either less than or greater than the carrier frequency. The displacement angle can be adjusted for Power width modulation switching strategies in order to minimize the losses incurred. This is important so as to improve the efficiency of a multilevel inverter. In the review above, a multilevel topology for a cascaded inverter has been proposed which makes use of only a single DC power source. With the model specifications as described, voltage level of the capacitors can be easily modified and controlled with the help of switching angles chosen at modified index such that harmonics are eliminated from the output waveform. In fact, just any type of multilevel inverter can be created by altering and modifying the required voltage levels. A sinusoidal pulse width modulation scheme is used in the dissertation design which undoubtedly has more advantages as compared to other modulation schemes. All the switching functions and operational techniques are discussed in detail. Additionally, they are also compared to the old three level pulse width modulation inverters with respect to improvised output waveforms, small filter size and the like advantages. Multilevel inverters have proved to be a more efficient and practical approach for reducing harmonics in ac waveforms and for increasing power. (�L. M. Tolbert�, 1999) A few most important advantages of pulse width modulation inverters are as follows: 1. They minimize the dv/dt at the inverter output. 2. The series connection used in the multilevel pulse width modulation inverters permits a higher voltage irrespective of increase in voltage stress on switches. 3. As compared to a single cell inverter, a multilevel inverter can attain lower harmonics at the same frequency distortion due to increased levels of output waveform. (Dhana Prasad Duggapu et al / VSRD International Journal of Electrical, Electronics & Comm. Engg. Vol. 2 (5), 2012). 4. Refined power quality. 5. Better voltage capability. 6. Reduced switching loss. 7. With an efficiency higher than 98% due to minimum switching frequency. 8. They can be used to improve the dynamic stability and power quality for utility systems. 9. They can also be used to drive applications. 10. They are best suited for medium to high power appliances. This is how multilevel inverters find their usage in multiple fields. Design and approaches-Chapter-33. 1 IntroductionSeveral new energy resources have been introduced nowadays due to constantly soaring costs of fossil fuels and there dependency. At the same time, fossil fuels also have a negative impact on the physical environment. Accordingly, the new energy products are mainly renewable sources of energy. Owing to the presently prevailing energy dearth all throughout the world, photovoltaic power systems are replacing a lot of other non-renewable energy sources. This section of the paper will talk about the data collected, approaches used, data analysis and data sources used. It starts with the data collected and approaches used in the dissertations. With an aim to design and build a multilevel inverter connected to photovoltaic array, each single phase of the inverter comprises of two H-bridge cascaded inverters which in turn will be connected to double grid transformers in order to produce 5 voltage levels. 3. 2 Research DesignMultilevel inverters have fetched a huge attention in the recent research work mainly in high power applications. There are twofold advantages of multilevel inverters. First, due to series connection of power semiconductor modules, the voltage stress across each converter is reduced. Second, the quality of voltage generated enhances with the number of voltage levels. Thus, the waveform resolution increases and the filtering technique gets reduced due to improvised resolution in the voltage harmonics. The dissertation design below comprises of a hybrid multilevel inverter. There are two full bridge inverters and corresponding transformers with each phase of a multilevel inverter. With the different turn ratios of the transformers, the level of output voltage differs. Figure 7 Hybrid multilevel inverter with a 9 level output voltage. The full bridge inverter known as the main circuit is connected to a 1: 3a transformer and a full bridge inverter circuit known as an auxiliary circuit. The corresponding output voltage waveform of each stage corresponds to 5-level. Cascaded transformers are used owing to certain advantages. Some of them are listed as follows: 1. Cascaded transformers have a leakage reactance which provides a better harmonic filtering capability to the inverter voltage. 2. They boost the number of output voltage levels and in turn lower the switching frequency of the power equipment unlike other usual multilevel inverters. 3. In order to match the ac utility, cascaded transformers boost typically low solar voltage. The proposed hybrid multilevel inverter produces a single phase output voltage waveform. Here, V1 corresponds to the output voltage of the inverter connected to the transformer with turn ratio 1: 3a and V2 stands for the output voltage of the inverter which is connected to the transformer with turn ratio 1: a. The final voltage V is calculated by adding the two voltages

V1 and V2. For higher levels, the number of output voltage varies with different levels corresponding to different combinations of cascaded transformers. The levels are denoted by N where n equals to 1, 2, 3�. n values. Here, n corresponds to the number of selected transformers in each stage. Figure 8 Output waveform of 5-level output voltageThe basic design of the projected grid connected photovoltaic system is as shown below: Figure 9 Design of a projected grid connected photovoltaic systemPV strings are not equally distributed in order to obtain DC voltage s at the output of DC/DC converters. The proposed system has numerous PV modules, a multilevel DC/AC power converter, a power transformer and a DC/CD power converter. A multi string technology is used for the PV modules arrangement. The output of these inverters thus obtained is the DC power supply of the multilevel DC/AC power converter. A sliding mode controller is also used in order to control the proposed multilevel power inverter. To control the obtained multilevel power converter, a sliding mode controller is used. Taking into consideration unique input DC voltage for two single phase inverter and for the four wire inverter, it allows an extension in the number of achievable voltage levels at the multilevel output. Thus, in order to achieve this target, a DC/DC power converter connected to an inverter must produce a V voltage while at the same time DC/DC converter connected to the inverter must produce a 2V voltage at the output (V. Fern�o, J. F. Martins, D. Foito, H Chen. (2012). 3. 3 Switching states and Output levelsOn applying correct switching functions to the above topology, the ultimate output voltage level can be calculated by rating an integer to an input voltage source (Vdc). For instance, as shown in figure, we select cascaded transformer turn ratios as T. 1a and T. 2a to obtain a 9 level output voltage waveform. The 5 levels comprise of 0, +Vdc, -Vdc, +2Vdc, -2Vdc. In order to get an output frequency of 50 Hz, a time switching time pattern is designed during 20ms which resultsf=, 1-t.=, 1-20ms.= 50Hz. The switching pattern is designed according to the path of the current through the specific switch which will result a switching time patterned for each switch. Below an image the switching pattern that I have used. Figure 10 Output waveform of 5-level output voltage with switching pattern3. 4 Control StrategyAt present, the modulation techniques available for multilevel inverters are basically- phase shift method, selective harmonic elimination method, space vector modulation, staircase PWM method and sub harmonic modulation. Out of all these, space vector PWM (pulse width modulation) is the best to be used as it directly makes use of the control variable as given by the system and correctly identifies each switching vector as a unique point (x, y) in space. It is best suited for digital signal processing implementation and it can also optimize switching sequences. As the level increase, it is difficult to realize the conventional space vector modulation based on three-level or two-level inverters. These days, some modified methods have been introduced to improvise the space vector modulation of inverters at any level. Out of those few, the easiest to implement is carrying out Pulse width modulation using the switching pattern which is shown in the previous section. A 5-level inverter is taken as an example. An N-level system makes use of three voltages Va, Vb and Vc mean the unit value of voltage attained from three cascaded inverters A, B and C. This calls for a switching state where Va, Vb and Vc are three different voltage levels. Let us take [Vx, Vy] as the coordinate value of Vref in x-y coordinates and [Va, Vb, Vc] as the coordinate values of Vref in three phase system. Now, x-y is distributed into six different sectors called 60 degree coordinates such that all six sectors formed are exactly equilateral triangles and other 5 sectors are converted to sector 1 or between 0 to 60 degrees. In x-y coordinates, Vref of phase angle is ? * which lies between 0-360 degrees and S denotes the number of sector where Vref is. ? refers to the phase angle of Vref after getting transformed to sector 1 or 60 degree coordinates. 3. 5 Controlling UnitFigure 11 Arduino microcontrollerThe controlling unit basically consists of an Arduino Microcontroller which makes use of an incremental conductance algorithm in order to trace the highest point and also to impart the power width modulated pulse to the DC-DC inverter. The main advantage of using this microcontroller as a controlling device involves the key features used for this system. These include the following:* A ten bit analog to digital inverter multi channel.* Low power consumption* Two compare, capture power width modulation modules. 9- level Inverter TopologiesBelow depicted is the configuration of a single phase nine level diode clamped converters: Figure 12 9 level inverter schematicIn the above configuration figure (12) that of a single phase nine level cascaded H-bridge inverter, capacitors can be used at the input to complete voltage divider circuits. In case of an n-level topology, there has to be n-1 corresponding switches of each phase. In order to ensure that the switches connected in series are subject to predetermined voltage, diodes can be incorporated with switches. Consequently, a predefined voltage of a series capacitor is connected to the output. The output waveforms thus obtained for a nine level inverter single phase are as follows:

Figure 13 output waveform of 9 level inverter3. 6 diode clamped inverter. Diode clamped inverters are more preferred as compared to other topologies because it is light in weight, cost effective and low volume because of the use of less number of capacitors. Moreover, it can be directly connected to a single phase DC link voltage. But, at the same time they are not preferred more because clamping diodes are prone to high voltage stress when more than three levels are used and thus series connections of clamping diodes is introduced. They also tend to limit the output voltage value attained for a particular DC-link voltage. When operated at huge modulation indices and low power factors, the corresponding three level topology experiences low frequency ripple in the neutral point. In case of a capacitor clamped multilevel topology, voltage clamping can be achieved with the help of capacitors that float with respect to earth�s potential. In a three-level three-phase flying capacitor inverter, each phase of the topology is considered as an imbricate cell where a fixed number of predefined capacitors are connected in series to produce an output voltage. An imbricate cell is basically the primary building block of a floating capacitor multilevel inverter. One switch out of the two pairs should be ON for a perfect connection to establish between the output through capacitors and DC-link potential. To avoid short-circuiting the capacitor, it should be made sure that both switches in a pair are not in the ON state at one particular time. SH2SH1Va0iCf1Offoff00Offon0. 5Vdc-iaOnoff0. 5VdciaOnonVdc0Table 2 switching pattern of diode clamped inverterThe table above depicts all possible state levels of switches in a three-phase three-level flying capacitor inverter. With different combinations of switches, same output voltage is achieved. This condition well guarantees balanced voltages in the floating capacitors by utilizing a suitable modulation scheme. This is also an important difference between a diode clamped and flying capacitor inverter. Mentioned that the current level is the same through all floating capacitors, they should also have the same capacitance flowing across in order to produce similar magnitudes of their ripple voltage. Considering both series and parallel connections depending on the same component, for instance Cf2 capacitor needs 4 times number of components as needed by capacitor Cf1. A half-bridge topology on the other hand has to be added to obtain even number of levels. The modularity of a half-bridge topology is a significant feature. At the same time, the DC-link voltage must be isolated is a huge loophole in practical implementation of cascade inverters. A couple of independent DC power supplies are needed and these are provided as forms of fuel cells, separate batteries, isolated transformer outputs and PV arrays. Every single cell should be used in a cyclic pattern during each half cycle of the supply period in order to balance the power imparted by the DC voltage devices. An additional advantage of this circular technique is that it achieves the same frequencies on switching for all types of switching devices. In the figure (14) above five similar inverter of series connection of modules are connectedFigure 14 11 level inverter schematicto produce a single phase 11 level cascade inverter. Different DC sources of same magnitude feed all the connected modules of the circuit. Ranging from + Vpu to �Vpu, the 11 level cascade inverter has 11 different voltage levels. The traditional eleven level inverter can be transformed to a 123-level inverter with the help of DC voltage sources with magnitude ranging from n0: n: n3: 2n3: 10n.